FOLLOWING THE PAPER TRAIL
THE IMPACT OF MAGAZINE AND DIMENSIONAL LUMBER PRODUCTION ON GREENHOUSE GAS EMISSIONS: A CASE STUDY

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DEDICATION

Today an army of environmental scientists are questing for the knowledge that will empower us to achieve a healthy and sustainable Planet Earth. The villains are those who refuse to recognize that human behavior now may lower the quality of life for generations to come. We do best when we seek inter-generational enrichment. –G.W. Miller

In memory of Mr. G. William Miller

G. William Miller (1925-2006), former Chairman of The Heinz Center Board of Trustees, joined the Board in 1999 and retired in 2005. His background involved both a successful business career and a dedication to public service including Chairman of the Board of Governors of the Federal Reserve System. Mr. Miller also served as Secretary of the Treasury under President Carter and as Chairman of the Advisory Council of the President's Committee on Equal Employment Opportunity under President Lyndon Johnson. He was also a member of the National Endowment on the Humanities, a director and then Chairman of the National Council of Business and Chairman of the Industry Council to promote jobs for Vietnam veterans.

We dedicate this study to the memory of G. William Miller, a man of wisdom, graciousness, and commitment to the common good.

Contents

PREFACE

Canfor, The Home Depot, Stora Enso in North America (SENA) and Time Inc. (listed in alphabetical order) commissioned the greenhouse gas (GHG) life-cycle analysis (LCA) of two magazine chains and a dimensional lumber chain. The collaboration of the four companies in this project reflects the flows of (i) Canfor wood fiber to The Home Depot, a large do-it-yourself remodeling and construction retailer, and (ii) flows of Canfor kraft pulp, SENA wood fiber and SENA kraft pulp used to produce magazine paper for *Time* and *InStyle* magazines. The Heinz Center for Science, Economics and the Environment, an environmental non-governmental organization (NGO), helped the participants identify and address relevant environmental issues. The participants undertook the self-initiated study to quantify sources of GHG emissions for each major step in the magazine and dimensional lumber product chains. This life-cycle analysis provides valuable information that company managers can use to increase efficiency in the production of paper and wood products by decreasing the demand for energy resources and reducing GHG emissions. We only examined the major components of GHG budgets in this study.

This study is unlike other forest product LCA studies in that the participants in this study provided their product-specific data. A brief profile of each of the participating companies and the NGO are provided below, with participants listed in alphabetical order.

Canfor

Canfor Corporation is a leading integrated forest products company based in Vancouver, British Columbia. The company is the largest producer of softwood lumber and one of the largest market pulp producers in Canada. It employs 7,046 people at its operations and offices in British Columbia, Alberta and Washington state.

Commitment to the environment has been a part of Canfor's corporate culture since the company's inception. Today, Canfor is a leader in forestland certification. All of the forestlands where it operates are certified to the ISO 14001 standard, and currently 85% of its forest tenures, or approximately 16 million hectares, have been certified under the Canadian Standards Association Sustainable Forest Management standard (see Appendix 1). The Chetwynd forest area included in this study is certified to the Canadian Standards Association Sustainable Forest Management standard. The company's pulp and paper facilities are registered under both the ISO 9001 and 14001 standards. For further information on Canfor's certification please follow this link: http://www.canfor.ca/sustainability/news.asp.

All forestry activities within Canfor are guided by a set of Forestry Principles that were developed by a multi-disciplinary Canfor task force. A panel of external experts and stakeholders, including members of the environmental community, also assisted with the development of the Principles. The Principles are based on the tenets of ecosystem management, continuous improvement, public involvement and third-party verification of performance. Canfor views these Principles as the fundamental basis for further improving its existing sustainable forestry practices, ensuring the transparency of its operations and fulfilling registration requirements for eco-certification. The Principles were approved and subsequently introduced to all Canfor operations by the end of 1999. For more information or a copy of the Principles please follow this link:
http://www.canfor.com/sustainability/principles.asp

Canfor is an industry leader in reducing greenhouse gas emissions from fossil fuels and expects that during the first Kyoto commitment period it will have met or exceeded national targets for reducing greenhouse gas emissions. For full details of the company submission to the Canadian GHG Voluntary Challenge and Registry follow this link: http://www.canfor.com/sustainability/corporate/initiatives/ghg.asp.

The Home Depot

At The Home Depot®, we are committed to conducting our business in an environmentally responsible manner. From our progressive consumer education programs, to our commitment to carry certified "green" products, to efficiently designing our stores, the company is dedicated to making a positive environmental impact every day and making communities better places for generations to come.

The Home Depot's Environmental Principles

Raise awareness of products and practices that reduce our customers' impact on the environment and help them maintain healthier homes.

Provide our customers with products that make sustainable use of natural resources, eliminate unnecessary packaging and are accurately labeled.

Conserve natural resources by using energy and water wisely, and seek further opportunities to improve the resource efficiency of our stores and supply chain.

Minimize waste by recycling and using materials and products with recycled content.

Maintain programs and procedures to ensure compliance with environmental laws.

Provide a healthy and safe environment for our associates and neighbors.

Environmental Awards Snapshot

ENERGY STAR Retail Commitment Award from the U.S. Environmental Protection Agency (2005)

Mow Down Pollution: Gold Medal prize in the Climate Change category of the 2005 Canadian Environment Awards presented by *Canadian Geographic Magazine*

The Home Depot Canada President Annette Verschuren received the Award of Excellence in Market Transformation from the Toronto Green Awards (Canada – 2005)

No. 1 Most Admired Specialty Retailer from *Fortune* magazine (2005 and 1993 – 2002): The Home Depot's record of environmental and community responsibility served as one of the eight ranking criteria.

The Home Depot
(continued)

Advocate of the Year 2004 from Office of Energy Efficiency (Natural Resources Canada)

National Product Campaign Award from the U.S. Environmental Protection Agency (2004)

National Product Campaign Award from the U.S. Environmental Protection Agency (2003)

Flex Your Power Energy Conservation Award (California – 2003)

Visit http://corporate.homedepot.com/wps/portal/!ut/p/.cmd/cs/.ce/7_0_A/.s/7_0_11P/_s.7_0_A/7_0_11P for more information about The Home Depot's environmental and social responsibility initiatives.

Founded in 1978, The Home Depot is the world's largest home improvement specialty retailer and the second largest retailer in the United States, with fiscal 2004 sales of $73.1 billion. The company employs approximately 325,000 associates and has 1,988 stores in 50 states, the District of Columbia, Puerto Rico, 10 Canadian provinces and Mexico. The company has announced plans for retail expansion into China. The Home Depot has been recognized by *Fortune* as the No. 1 Most Admired Specialty Retailer for 2005. Its stock is traded on the New York Stock Exchange (NYSE:HD) and is included in the Dow Jones industrial average and Standard & Poor's 500 index.

The H. John Heinz III Center for Science, Economics, and the Environment

History and Mission

Established in December 1995 in honor of Senator H. John Heinz III, The Heinz Center is a nonprofit, nonpartisan institution dedicated to improving the scientific and economic foundation for environmental policy through multi-sectoral collaboration. The membership of the Center's Board of Trustees, its steering committees, and all its committees and working groups reflect its guiding philosophy: that all relevant parties must be involved if the complex issues surrounding environmental policymaking are to be resolved.

Approach

Focusing on issues that are likely to confront policymakers within two to five years, the Center creates and fosters collaboration among industry, environmental organizations, academia, and government in each of its program areas and projects. The active involvement of these four sectors in all aspects of environmental policymaking—from identification of a problem through the crafting of recommendations to implementation of a policy—produces robust solutions to the environmental challenges that face the Nation. This philosophy, and its implementation in the Center's everyday operations, means that leading policymakers and practitioners from government, industry, environmental organizations, and universities are able to work together to identify pressing environmental challenges and to agree upon ways of meeting those challenges.

Stora Enso in North America

Stora Enso, is a global integrated paper, packaging and forest products company. In North America, Stora Enso is a leading producer of coated and supercalendered papers for the printing and publishing industries, and a premier producer of speciality papers. Other products include newsprint, elemental chlorine-free kraft pulp, totally chlorine-free mechanical pulp and recycled pulp from recovered paper.

In North America, Stora Enso has papermaking operations in Biron, Kimberly, Niagara, Stevens Point, Whiting and Wisconsin Rapids, Wisconsin; Duluth, Minnesota; and Port Hawkesbury, Nova Scotia, Canada. To learn more about Stora Enso's operations in North America, visit: http://www.storaenso.com/na.

Environmental excellence is an essential component of our company's mission, vision and values. We believe high business standards and high environmental standards must be mutually compatible. The region's pulp, paper and board manufacturing facilities have implemented third-party certified ISO 14001 Environmental Management Systems. Our Environmental Management Systems (EMS) were developed addressing the significant environmental aspects and impacts of our operations. The EMS is a continual improvement process that focuses on minimizing environmental impacts. Our forestry management procurement operations have also implemented third-party certified ISO 14001 Environmental Management System. The region's Canadian forestlands are certified to the ISO 14001 standard and to the Canadian Standards Association Sustainable Forest Management standard and the Sustainable Forestry Initiative® (see Appendix 2). For more information about ISO 14001 registration and about Stora Enso forest certification, please link to http://www.storaenso.com\sustainability.

Stora Enso's strengths in abating the effect of climate change are based on its use of a renewable resource: wood. We will work in joint efforts with our partners, customers, other businesses and society at large to further abate climate change. The North American region is a charter member of the Chicago Climate Exchange, a voluntary program for reducing greenhouse emissions through market-based trading. For more information please link to http://www.chicagoclimatex.com.

Time Inc.

Time Inc. is the world's leading magazine company, publishing over 150 titles with more than 300 million readers. In 2005, Time Inc. magazines accounted for 23% of the total advertising revenue of U.S. consumer magazines. *People*, *Time* and *Sports Illustrated* were ranked one, three and four in ad revenue respectively.

Time Inc. is a wholly-owned subsidiary of Time Warner, the world's leading media and entertainment company, whose businesses include interactive services, cable systems, filmed entertainment, television networks and publishing.

In March of 2006, Time Inc. released its first Sustainability Report. In addition to publishing its Sustainable Paper Purchasing Policy, the report highlights the company's initiatives in many areas including:

ReMix: Recycling Magazines is Excellent

ReMix is a program designed to dramatically increase the recovery rates of magazines and catalogs. Based on a study conducted by International Paper and Time Inc., the recovery rate of magazines and catalogs from the home is only 17%. The two companies joined with the National Recycling Coalition to start the ReMix program with pilot efforts in Boston and Prince George's County, Maryland. In 2005, we added Greater Milwaukee to the list of cities. The partners have utilized various media to promote recycling, including magazine advertisements which have run in 34 magazines, reaching an audience of 85 million with a value of $3.5 million. As of early 2006, results show an increase in recovery rates of 23% in Boston and 11% in Prince George's County. In 2006, we plan to launch ReMix in 2 additional cities.

CSF: Certified Sustainable Forestry

CSF is Time Inc.'s effort to revolutionize forestry certification in North America and other key wood baskets. The goal of the program is to increase the amount of fiber used in our magazines that is independently certified to a credible standard from 25% in 2002 to 80% by the end of 2006. Our focus has been on the fiber coming from small non-industrial landowners, who supply over 70% of all the fiber to mills in the United States. By promoting master logger programs in Maine and other states and provinces, supporting the

Time Inc.
(continued)

development of credible group certification standards and speaking at numerous events to small landowners, loggers, foresters and government officials, we are seeing major growth in the numbers of private land being certified. In addition, over 15 million acres of public lands in Maine, Wisconsin, Minnesota and Michigan have been certified in the past 2 years. By the end of 2004, 58% of all the fiber in Time Inc.'s products met our CSF standards. These efforts have been largely focused in the U.S. and Canada, but we have also been active in Europe, as shown below.

From Russia …with Transparency
This project is an effort to promote improved social responsibility efforts in the Russian forest sector with partners Axel Springer, Random House (UK), Stora Enso, Tetra Pak and the NGO Transparency International. Our focus is on worker health and safety, illegal logging, corruption and forestry certification. For more information go to: www.tikhvinproject.ru.

Paper Working Group
Time Inc. is a founding member of the Paper Working Group, whose goal is to promote the supply of environmentally preferable paper. The 11 founding members have developed the EPAT (Environmental Paper Assessment Tool) to measure a paper company's relative sustainability performance. The project is organized by Metafore, a Portland, Oregon based non-profit. In addition to the 11 founding companies, 10 additional companies have joined in as early adopters of the project. The EPAT is expected to be released in May of 2006.

For additional information and copies of our sustainability report, please reach us at sustainability@timeinc.com.

EXECUTIVE SUMMARY

The objective of this study was to conduct a greenhouse gas life-cycle analysis (LCA) for two forest product chains: (1) pulp and paper for the production of magazine grade paper, and (2) the production of dimensional lumber for construction, remodeling, and do-it-yourself projects. The wood fiber used to make the magazine paper was obtained from forests in the Black Hills region of the U.S. and the Great Lakes regions of the U.S. and Ontario, Canada. A portion of the kraft pulp used was produced from sawmill residual chips originating from the Chetwynd Forest in interior British Columbia, Canada, and several other smaller forest regions in Canada. The wood for the dimensional lumber was obtained from the Chetwynd Forest. The participants undertook this self-initiated study to better understand the sources of greenhouse gas (GHG) emissions for each product chain and to use this information to identify management opportunities that may reduce net GHG emissions.

The LCA included all major direct and indirect carbon and GHG emissions from activities including harvest, transportation of wood and other raw materials to the mills, manufacturing, transportation of finished products to end user (including the transportation to converter stations), recovery and recycling of products, and disposal of waste. The GHG emissions

were classified as direct or indirect[1] using standard protocols (WRI/WBCSD 2001). Based on the most current literature review (Johnson and Curtis 2001), we assumed that harvesting did not significantly affect soil carbon content, but we examined the sensitivity of this assumption on the carbon budget of the magazine and dimensional lumber product chains.

This study differs from other LCA for forest product chains because the participants provided data for each process in each chain, except for data used to estimate the final fate of paper and dimensional lumber. The analyses were restricted to 2001 because this was the most recent year for which all participants could provide data for all the processes in the magazine and dimensional lumber chains. It is difficult to determine if the results and conclusions of the study would differ if another year were selected, but we address this issue in the discussion section of the report.

The life-cycle analysis of the dimensional lumber chain revealed that 0.22 tons of carbon, or 0.83 t CO_2-eq, were emitted per ton of dimensional lumber. The final fate of the dimensional

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[1] Direct CO_2-eq emissions were defined as emissions from forest harvest activities, pulp and paper manufacturing including on-site transportation emissions, printing, and dimensional lumber production. Indirect CO_2-eq emissions were identified as transportation emissions (e.g. fiber and other raw materials to the manufacturing facilities, finished manufactured product to printing houses and retail outlets, printed magazines to newsstands and subscribers, and transportation related to recovery, recycling and disposal of waste).

lumber was estimated to be 65% incinerated and 35% landfilled, of which only 6% of the carbon contained in the wood placed in the landfill was released to the atmosphere in year 2001. This estimate was based on the assumption that the waste pool was in steady state for 2001. The relative contributions from the processes generating CO_2-eq emissions in the dimensional lumber chain were: forest management plus harvesting (< 1%), transportation of wood to the sawmill (2%); sawmill emissions (2%), transportation and distribution of dimensional lumber to consumer (94%), miscellaneous losses from by-products and final fate (2%). Indirect emissions comprised 98% of total emissions for the dimensional lumber chain.

The LCA of the magazine chain revealed that 0.32 tons of carbon (or 1.17 t CO_2 equivalents[2]) were emitted per ton of *Time* magazine produced, and 0.30 tons of carbon (or 1.11 t CO_2 equivalents) were emitted per ton of *InStyle* magazine produced, assuming 90% of unrecovered magazines were landfilled and 10% were incinerated (Paper Task Force 1995). CO_2 equivalent emissions were 5.8 times greater for *InStyle* than *Time* when emissions were expressed on a per magazine basis because the

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[2] The greenhouse gases considered in this study were carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Methane and nitrous oxide were multiplied by 21 and 310, respectively, to account for the greater global warming potential of these two GHG than CO_2 (NCASI 2002). CO_2 equivalent, henceforth denoted as CO_2-eq, was calculated as the sum of CO_2 plus the weighted sum of methane and nitrous oxide.

average weight was 5.5 times greater for an *InStyle* than *Time* magazine. The relative contributions from the processes generating CO_2-eq emissions in the *Time* and *InStyle* magazine chains were: forest management and harvesting (2% and 2%), transportation of all wood fiber (and clay) to the pulp and paper mills (8% and 3%), pulp plus paper mill emissions (61% and 77%), transportation of paper to magazine printers (1% and 1%), magazine printing (4% and 2%), transportation and distribution of magazines (8% and 5%), and final fate of magazines (16% and 10%). Indirect CO_2-eq emissions comprised 17% and 9 % of total GHG emissions for the *Time* and *InStyle* magazine chains, respectively.

Potential opportunities for reducing direct emissions of GHG from the magazine chain include increased: (i) energy use efficiency, (ii) pulp, paper, and printer mill production efficiency, (iii) utilization of renewable fuels to replace fossil fuels, (iv) utilization of combined heat and power production, and (v) efficiency of magazine newsstand sales through a better understanding of consumer purchasing habits. Potential opportunities for reducing direct GHG emissions from the dimensional lumber chain include increased: (i) energy use efficiency, (ii) production efficiency of older sawmills, (iii) utilization of renewable fuels to replace fossil fuels, and (iv) utilization of combined heat and power production. Opportunities for reducing GHG emissions from transportation include maximizing efficiency of transportation modes (e.g. truck vs. rail) and routes, and working with transportation providers to encourage fuel-efficient engine designs. Greenhouse gas emissions can be further reduced by replacing combustion of fossil fuels by hydro-electric, wind, solar and nuclear energy generation. The feasibility of increased use of these technologies will depend upon market forces and social acceptance. Consumers, governments, and society can all impact the paper and wood product chains by determining the final fate of paper and wood waste products.

INTRODUCTION

The atmospheric concentration of CO_2 has increased by 31% since 1750, with an average annual rate of increase of 1.5 ppm or 0.4% during the past two decades (IPCC 2001). The IPCC Special Report on Emission Scenarios (SRES) projects atmospheric CO_2 concentrations of 540 to 970 ppm by 2100. The large range in variations of atmospheric CO_2 concentration projections is due to differing scenarios for fossil fuel sources, economic development, world populations, and technological development. The atmospheric concentrations of methane (CH_4) and nitrous oxide (N_2O), two other greenhouse gases, are also increasing (IPCC 2001). The rapid rise of atmospheric CO_2 and other GHG concentrations is one of the most pressing environmental problems facing society today because of the various environmental, social, and economic problems caused by global climate change (IPCC 2001).

Forests play an important role in the global carbon cycle because they cover 65% of the total land surface, contain 90% of the total vegetation carbon and 80% of the total soil carbon in terrestrial ecosystems, and assimilate 67% of the total CO_2 removed from the atmosphere by all terrestrial ecosystems (Landsberg and Gower 1997). Forest carbon budgets are dynamic and change in response to environmental factors, disturbance, and management practices (Gower et al. 2003). One of the most dramatic changes to forest ecosystems is society's increased reliance on forests for fiber and fuel. Humans have changed or transformed 30 to 50% of the Earth's land surface to produce food and fiber, and these changes have directly and indirectly influenced the exchange of GHG between forests and the atmosphere (Vitousek et al. 1997, Wernick et al. 1998).

The forest carbon cycle, or C cycle, is comprised of a biological and an industrial C cycle (Figure 1). The biological C cycle is well studied relative to the industrial C cycle (Gower et al. 2003). A brief summary of the biological C cycle is provided in Box 1.

Few studies have quantified the carbon content of and emissions from wood and paper products. Humans consume approximately 270 x 10^6 tons of paper annually worldwide, and the pulp and paper industry consumes the fifth largest amount of energy of any industry in the world to meet the growing demand for paper (PPI 1996). Row and Phelps (1996) estimated the annual gross rate of carbon accumulation in forest products in the United States was 35 x 10^6 t C, and the use of wood-derived biofuel prevented the release of 50 x 10^6 tons of C from the combustion of fossil fuel in the United States. Many scientists who have studied forest product C budgets have suggested that forests products store C (Karjalainen 1994, Row and Phelps 1996, Karjalainen et al. 1996, Winjum et al. 1998, Skog and Nicholson 2000). However, their conclusions are based on gross C storage in the products and do not account for GHG released to produce and transport wood and paper products.

Life-cycle analysis (LCA) is a tool in industrial ecology used to evaluate the environmental burdens of a product or process by quantifying the energy and materials used and waste(s) generated from the manufacture of the product (SETAC 1993, Graedel and Allenby 2003). The results of a LCA are used to identify and evaluate opportunities to improve efficiencies and reduce waste.

Box 1.

Gross primary production (GPP), or total CO_2 assimilated by the vegetation, removes CO_2 from the atmosphere (Figure 1). Approximately 50% of the assimilated CO_2 is respired back to the atmosphere (Figure 1); this latter process is known as autotrophic respiration (R_A). Net primary production (NPP), or the annual net amount of biomass (or carbon) stored in vegetation, is the difference between GPP and autotrophic respiration. Carbon comprises 45-50% of plant biomass. NPP is allocated to long-lived tissues, such as stem wood, and short-lived tissues, including leaves and fine roots. The natural turnover of these tissues produces detritus (D) that is deposited as fine litter (e.g. leaf litter, fine twigs) and coarse woody debris (e.g. tree stems and large branches) and is slowly incorporated into the mineral soil carbon. Approximately 50-80% of the total carbon contained in the aboveground vegetation is removed when the forest is harvested (H), and the remaining tissues (e.g., foliage, branches, cull trees, and roots) return to the soil (Gower 2003). Soil surface CO_2 flux (S) is the sum of root respiration, a component of autotrophic respiration, and heterotrophic respiration. Heterotrophic respiration, the CO_2 released back into the atmosphere as a result of decomposition, is the second largest source of carbon flux in forest ecosystems. When heterotrophic respiration is subtracted from the sum of detritus input and harvest residue, the net difference determines if the soil carbon content increases or decreases. The difference between net primary production and heterotrophic respiration determines if the forest is a net carbon sink (NPP $>$ R_H) or net carbon source (NPP$<$ R_H). The rate of decomposition is dependent upon tissue type, environment, and disturbance.

Greenhouse gas LCA studies identify and quantify GHG emissions for all processes in the product chain. These data can be used to identify opportunities to reduce GHG emissions, management practices that can potentially increase carbon sequestration, and optimal disposal practices of end products.

A LCA should include the entire life-cycle of the product, or product chain, including extracting and processing the raw materials; manufacturing, transportation and distribution of the final product; and recycling and final fate of the product and by-products. The net emission of waste (i.e. greenhouse gases, solid waste, air pollution, etc.) is referred to as “product shadow.” Few LCA studies have been completed for forest products because they require cooperation from many manufacturers and users of wood and paper products. Consequently, most LCA studies for forest products have used industry-wide averages.

The objective of this study was to perform a LCA for two major product chains: (i) SENA and Canfor pulp used to produce SENA paper for *Time* and *InStyle* magazines and (ii) a Canfor sawmill and the production of dimensional lumber sold by The Home Depot and other retailers for construction, remodeling, and do-it-yourself projects. These two product chains are related, as the residual chips produced in the saw-milling process provide the raw material for the pulping process. Secondary products (e.g., trim blocks, wood waste, and chips) and end products from the paper and dimensional lumber chains were followed from production to final disposal. A complete accounting of the direct and indirect carbon and greenhouse gas emissions from harvest, transportation of wood and other raw materials to the mills, manufacturing emissions, transportation of finished products to end user, recovery and recycling of products, and disposal of waste was conducted using chain-specific data provided by participating companies to the extent possible.

METHODS

LCA Boundaries

The temporal and spatial boundaries of a LCA study must be clearly defined, but there are no clear guidelines for defining boundaries where there are complex sources of raw materials and energy required to produce the final product, and where there are different life spans for products, by-products, and waste comprising the chain (Grieg-Gran et al. 1998, Row and Phelps 1996, Skog and Nicholson 2000). We defined the study boundaries to include the flow of wood from the two major wood fiber procurement regions and the GHG emissions required to transport the wood fiber to the mills, all stages of the manufacturing processes of the primary product (magazines and dimensional lumber) and by-products, transportation of the forest products to consumers, the final fate of those products, and purchased power. The study focused on one paper product (consisting of two grades of paper for two magazines) and one dimensional lumber product, although other by-products and post-consumer waste were quantified (Figure 2). The production of multiple paper and wood products from forests is representative of the efficient, but complex, forest products industry.

The wood fiber procurement area, or “basket,” for the SENA mills consists of forests in the Black Hills region of the U.S., the Great Lakes region of the U.S., and Ontario, Canada (Figures 3-5). Wood fiber is transported by rail or truck to SENA’s Wisconsin Rapids Pulp Mill, Biron Mill and Whiting Mill. SENA also purchases kraft pulp to supplement the kraft pulp produced at the Wisconsin Rapids Pulp Mill. The Canfor Intercon pulp mill uses residual chips from the Chetwynd sawmill to produce kraft pulp, some of which is sold to SENA’s Whiting Paper Mill for the manufacture of paper. Pulp from the Wisconsin Rapids Pulp Mill is used at the Biron Mill and Whiting Mill to produce the paper used in *Time* and *InStyle* magazines. *Time* was selected because it is the flagship magazine for Time Inc., and it provides editorial coverage on a range of environmental issues. *InStyle* was selected because it is Time Inc.’s largest monthly magazine, and its entire body is printed entirely on SENA paper. Both *Time* and *InStyle* have wide readership over a large geographic region, and both magazines are sold as newsstand and subscription magazines.

The wood for the dimensional lumber was obtained from the Chetwynd Forest in interior British Columbia, Canada. The Chetwynd Forest provided roundwood to the Chetwynd sawmill for the production of dimensional lumber for The Home Depot and other lumber retailers.

Purchased power was also included in the analysis.

Production facilities in the magazine chain and dimensional lumber chain purchased power from energy grids that produce energy from one or more of the following sources: coal, natural gas, hydropower and nuclear. The latter two are considered to be carbon-neutral (US DOE 2002). Annual CO_2-eq emissions were estimated as the product of standard CO_2-eq emission factors for each energy source in the power grid. If the fraction of energy sources was not known, a state-wide average was used (Appendix III, US DOE 2002). Fuel cycle emissions, or the GHG emissions from the extraction of the fossil fuels, were not included.

This study is different from other forest product LCA studies in two important ways. First, to the maximum extent possible, we used forest- and mill-specific data rather than "industry-average" data that are often used by default because of the proprietary nature of these data (e.g., Blum et al. 1998, Ruth and Harrington 1998). Second, we included the GHG emissions for forest management, harvesting, transportation, production of the primary products, and the disposal of the end products. Studies to date have omitted one or more portions of the product chain (e.g. Côté et al. 2001).

Units

The SI (metric) system is the only international units of measure system. All units used in this paper are metric tons, unless noted otherwise. Greenhouse gases are commonly compared on the basis of their potential to cause global warming. Global Warming Potentials (GWPs) have been developed to convert non- CO_2 greenhouse gases (GHG) into an amount of CO_2 of equivalent warming potential (NCASI 2002). The methane (CH_4) and nitrous oxide (N_2O) emissions were multiplied by 21 and 310, respectively, to account for their greater GWP than carbon dioxide (CO_2) (IPCC 1996). CO_2-equivalents were calculated using the following equation, designated Eq. 1

$$CO_2\text{-eq} = [(CO_2) + (CH_4 \text{ x } 21) + (N_2O \text{ x } 310)]$$

More recent studies suggest that the GWP for methane and nitrous oxide should be 23 and 296 (IPCC 2001); however these values have not been widely adopted, and the older values were used to ensure comparability to other studies.

Direct and Indirect Greenhouse Gas Emissions

We adopted the World Resources Institute (WRI) / World Business Council for Sustainable Development (WBCSD) definitions for direct and indirect CO_2-eq emissions (WRI/WBCSD2001). Direct CO_2-eq emissions were defined as emissions from forest harvest activities, pulp and paper manufacturing including on-site transportation emissions, printing, and dimensional lumber production. Indirect CO_2-eq emissions were identified as transportation emissions. These included the transportation of fiber and other raw materials to the manufacturing facilities, finished manufactured product to printing houses and retail outlets, and printed magazines to newsstands and subscribers, as well as transportation related to recovery, recycling and disposal of waste. CO_2-eq emissions from many of the processes can be classified as direct and indirect sources, depending upon a variety of factors, and thus complicate the potential opportunities to reduce direct and indirect GHG emissions. In the discussion section we review the opportunities to reduce direct and indirect GHG emissions. Purchased power was included in the analyses. CO_2-eq emissions from purchased power were calculated as the product of mega-watt hours (MWh) of purchased electricity and a state-specific electricity emission conversion factor based on a relative fraction of fuel sources (U.S. Dept. of Energy 2002).

Greenhouse Gas LCA for the Dimensional Lumber Chain

The Chetwynd forest is located in interior British Columbia, Canada, northeast of Prince George. The average species composition of wood delivered to the Chetwynd sawmill in 2001 was mixed spruce (white and Englemann, 45%), lodgepole pine (43%), and subalpine fir (12%). The Chetwynd sawmill produced dimensional lumber, and the residual chips were transported to the Canfor Intercon kraft pulp mill (Figure 2).

SENA purchased approximately 29% of the total kraft pulp used in 2001, and the Intercon pulp mill supplied 8% of the purchased kraft pulp. Several other kraft mills in Canada provided the balance of the purchased kraft pulp, and we assumed that the GHG shadow was similar for Canfor and other purchased Canadian kraft pulp used to make SENA paper.

Harvest and Transportation of Wood Fiber to Sawmill

Canfor provided transportation distances, modes of transportation and total GHG emissions from transportation of logs from the Chetwynd Forest to the sawmills. We used Eq. I and the same fuel efficiency and GHG emission factors for the dimensional lumber chain as we used for the magazine chain.

Sawmill Production and GHG Emissions

Canfor provided the GHG emissions for 2001. The emissions included purchased power, mobile equipment in the mill, and sawmill production emissions.

Transportation of Dimensional Lumber to Consumers

Canfor provided transportation distances and mode of transportation for the other 22 regional distribution centers. Canfor and The Home Depot provided transportation distances and mode of transportation from distribution centers to the individual stores.

The dimensional lumber purchased by The Home Depot was transported to the Edmonton reload facility, or directly to one of five The Home Depot distribution centers (HDDC), where it is transported to The Home Depot stores (Figure 2). Additional dimensional lumber from the Chetwynd sawmill was sold to 22 regional distributors or private retailers.

Other By-Products

Residual materials from the Chetwynd sawmill are used for bioenergy or production of other products. Solid wood trim waste (e.g., trim blocks) is transported from the Chetwynd sawmill to a nearby facility where it is finger-jointed and used in construction of modular homes and component systems that require more stable structural framing than solid wood. Production of trim blocks in 2001 totaled 3,115 thousands of board feet (Mfbm). The life expectancy of pre-fabricated buildings was assumed to be 30 years (Row and Phelps 1996). Brown wood waste (bark) from the Chetwynd sawmill was transported 5 km (10 km round trip) by truck to another sawmill where it was incinerated. Sawdust waste was transported to a nearby sawdust pulp digester to make pulp.

Final Fate of Solid Wood Products

The estimated use of dimensional lumber sent to The Home Depot from Canfor was 45% for new home construction and 20% for large renovation projects. Of the remaining 35% of the dimensional lumber, approximately 20% was used for short-lived projects (doghouses, playhouses, partitions, etc.), and 15% was used for very short-lived (two years) projects. The lifespan of each end use was approximated using data obtained from industry averages based on a North America Home Builders study (Ahluwalia and Shackford 1993, Row and Phelps 1996). At the end of the product lifespan, a fraction of the material was assumed burned and the balance placed in landfills. Complete combustion of material that was burned was assumed. Only 6% of the carbon contained in landfilled dimensional lumber is released back to the atmosphere (Skog and Nicholson 2001).

Small amounts of waste from the Chetwynd sawmill and Intercon pulp mill were used in secondary production processes, with only 2% of total harvested fiber placed in landfills. In-store waste at individual The Home Depot stores was unknown, but an informal survey of dumpsters outside of stores suggested the waste was approximately 0.12% (J. Schwager, unpublished data). Few data are available on the final fate of dimensional lumber. Prior to 1972, most post-consumer waste was placed in dumps and burned; however, legislation has since phased out this practice. We examined the impact of different final fates on GHG emissions to better understand the effects of final fate practices and to explore different opportunities to reduce emissions in final step of the dimensional lumber chain.

Timber Harvest and Soil Carbon Dynamics

The calculations in this paper were based on the assumption that harvesting did not change soil carbon content during the rotation of a stand. The effects of harvesting on long-term soil carbon dynamics are highly variable and appear to be dependent upon forest type, harvest method and utilization rate (Johnson 1992, Johnson and Curtis 2001). On average, clear-cut harvesting does not significantly change soil carbon content (Johnson and Curtis 2001, Laiho et al. 2002). These results are consistent with two recent studies that examined the effect of harvest type (clear-cut versus selective tree removal) on soil carbon content for northern hardwoods in northern Wisconsin and time since clear-cut harvest of a boreal mixed wood forest. These studies are especially relevant because they are similar to the major forest ecosystems examined in this study. Mineral soil and forest floor carbon content did not differ significantly among managed even-aged (clear-cut), managed uneven-aged (selective removal), and unmanaged old-growth northern hardwood forests (Gower and Gries 2003). Similarly, forest floor and mineral soil carbon content did not differ significantly among 10-, 18-, 30-, and 65-year-old boreal mixed wood stands that were clear-cut and harvested using similar management practices (Gower et al. 2003). We included simulated soil C losses for the Chetwynd

Forest (Seely et al. 2002) to determine the sensitivity of the GHG shadows for the magazine and dimensional lumber product chains to assumptions about the effect of harvesting on soil C dynamics.

Site preparation and planting (versus natural regeneration) are also potential sources of GHG emissions and should be included in life cycle analyses. SENA planted 0.5% and site prepared 0.5% of their forestlands in Wisconsin annually during the past five years (T. Tollefson, SENA, unpublished data). The fraction of total lands planted and site prepared each year would be considerably lower if all SENA procurement lands (including those outside Wisconsin) in 2001 were included; therefore, the exclusions of site preparation and planting emissions has minimal effect on the analysis.

Roundwood volumes were tallied by species and converted to biomass using air-dried, species-specific gravity (mass/volume) values (USDA Forest Service 1987). Biomass was multiplied by 0.50 to estimate the carbon content of wood for all analyses in the paper (Gower et al. 1999).

CO_2-eq emissions from harvesting (harvest plus skidding logs to the landing) for all SENA's fiber procurement regions were calculated as the product of 1.47 units of diesel per unit volume of wood multiplied by both the total volume of wood harvested and by the CO_2-eq released per volume of diesel fuel (U.S. Bureau of Transportation Statistics). CO_2-eq emissions for harvesting of timber from the Chetwynd forest were calculated in a similar manner, with two notable exceptions: the harvest emissions included road building, and different harvest emission coefficients were used for normal and difficult terrain.

Transportation of Wood Fiber and Clay to the Mills

SENA provided GHG emissions data for transportation of chips and roundwood to the Wisconsin Rapids Pulp Mill (WRPM), where kraft pulp is produced, and GHG emissions data for the transportation of all wood fiber and clay to the integrated pulp and paper Biron Mill and Whiting Mill, which produce mechanical pulp and use kraft pulp to manufacture paper. Kraft pulp is purchased from several kraft pulp mills in Canada, including the Canfor Intercon kraft mill in British Columbia, Canada. Canfor provided data for the Intercon pulp mill that supplied pulp to SENA's Whiting Mill, and we assumed the GHG shadows from the other kraft pulp mills in Canada were similar to that of the Canfor kraft pulp mill.

Harvested wood fiber was transported to pulp and paper mills using diesel truck, rail, or both. Transportation emissions from truck (E_T) and rail (E_R) were calculated using the following equations, designated Eq. 2 and 3, respectively.

[Eq. 2]

$$E_T = \frac{\text{loads}}{\text{year}} \times \frac{(\text{mean distance})}{\text{load}} \times \frac{\text{volume of diesel}}{\text{distance}} \times \frac{CO_2\text{ emissions}}{\text{volume of diesel}}$$

[Eq. 3]

$$E_R = \frac{\text{destination distance}}{\text{year}} \times \frac{\text{wood mass}}{\text{load mass}} \times \frac{\text{vol. of diesel}}{\text{distance}} \times \frac{CO_2 \text{ emissions}}{\text{vol. of diesel}}$$

The mean distance was doubled to account for an empty return haul, unless otherwise noted (e.g., truck or rail hauled another commodity on the return trip). Truck fuel efficiency was assumed to be 2.58 km/liter (6.1 miles/gallon) of diesel (U.S. Bureau of Transportation Statistics), and rail fuel efficiency was assumed to be 177.54 tons-km/liter (420 tons-miles/gallon) (Association of American Railroads).

Clay is a component of the coating used to manufacture *Time* and *InStyle* magazine paper. Clay was transported by rail from Georgia to the Biron Mill and Whiting Mill. CO_2-eq emissions from the transportation of clay to the Biron Mill and Whiting Mill were calculated using Eq. 2, only substituting clay mass for wood mass.

Pulp and Paper Mill Production and GHG Emissions

SENA provided GHG emissions for the Wisconsin Rapids Pulp Mill, Biron Mill and Whiting Mill. Kraft and mechanical pulps were used to produce SENA magazine paper. The two pulps have different energy requirements and product attributes. Kraft pulping is a chemical process that produces black liquor, which is burned in a chemical recovery unit to reclaim pulping chemicals and generate steam or electricity. Black liquor is a by-product of the pulping process, and is therefore considered to be a renewable (e.g., carbon neutral) energy source (NCASI 2002). An advantage of carbon neutral energy sources is that they reduce dependence on fossil fuels. The pulp yield per ton of wood is lower for the kraft process than for the mechanical pulping processes because the chemicals extract lignin and other constituents of wood fiber. Blum et al. (1998) reported bleached and unbleached kraft pulping yields of 0.45 and 0.57 tons of pulp per ton of dry wood, respectively. Mechanical pulping efficiency ranges from 0.8-0.95 tons of pulp per ton of dry wood, depending upon species, however the process requires more net energy input than chemical (kraft) pulping. Also, the energy consumption is 2.1 times greater for thermo mechanical pulp production than stoneground wood pulp production.

The annual CO_2-eq emissions were calculated for all pulp and paper manufacturing operations and mobile equipment used in each mill. Fuels used in the pulp and paper operations were classified as non-renewable (e.g. coal, natural gas, propane, and fuel oil) or renewable (wood waste and black liquor) following national energy source guidelines (WRI /WBCSD 2001).

Transportation of SENA Paper to Printers and Printer Production

SENA provided transportation distances and mode of transportation (truck versus rail) for shipping SENA paper to the printers. Time Inc. provided data for the amount of SENA paper used for *Time* and *InStyle* magazines, average (for 2001) weight of a *Time* and *InStyle* magazine, and magazine production quantities.

InStyle was printed exclusively at one printing plant on 100% SENA paper. *Time* magazines were printed at six printing plants, but one printer did not use SENA paper in 2001 and was excluded from the study. A second printer did not provide printing emissions for 2001; therefore we used the average t CO_2-eq emissions/ton magazines printed calculated from the other five printers. A seventh printer printed four-page advance forms that were transported by truck to the other six printers. Transportation emissions of the advance forms were not included because they were transported with other material to the printers, and those GHG emissions were already included. The annual CO_2-eq emissions from the transportation of paper to each printer were calculated using Eq. 1.

Each printer provided estimates of total annual GHG emissions based on purchased electricity and natural gas. The annual CO_2-eq emission from each printer attributed to *Time* or *InStyle* magazine was estimated as the product of the ratio of SENA paper to total printed paper used multiplied by total printer emissions.

Distribution of Printed Magazines

Time Inc. provided data for magazine transportation and redistribution routes, including distances, the type of truck, percentage of the cargo freight weight attributed to *Time* or *InStyle* magazines, and whether the truck back-hauled empty or with another product. Each printing plant provided data summarizing weekly (or monthly in the case of *InStyle*) production, weight, and percent of subscription and newsstand magazines recovered for recycling.

Time and *InStyle* magazines are sold as subscriptions and on newsstands, and each are transported to the consumer using different processes. Newsstand magazines are transported directly to wholesalers or to drop-delivery units (i.e., break-up centers) where they are combined with other cargo, transported to wholesalers, and finally delivered to retailers, where they are purchased by consumers. Subscription magazines are transported from the printer to regional postal units, where they are combined with other mail and transported to local postal units for delivery to consumers.

Diesel trucks provide the dominant mode of transportation. CO_2-eq emissions were calculated as the product of total distance and fuel efficiency per unit of fuel consumed, using Eq. 1. CO_2-eq emissions were prorated by fraction of total cargo mass when magazines were transported with other cargo (newsstand) or mail (subscription). CO_2-eq emissions were calculated for a round trip, unless the truck transported other cargo on the return trip, in which case a one-way CO_2-eq emission was calculated. United States Postal Service diesel tractor-trailer trucks were used to transport magazines from the six printers to delivery-drop units (DDU). Equivalent CO_2-eq emissions for trucks were calculated as the product of the number of trucks, the average distance that could be covered in an average 8- to 10-hour day, and the assumed distance per unit of diesel fuel consumed and CO_2-eq. emission per unit of fuel consumed. The transportation emissions from local post offices to customers were not included because we were unable to quantify the fraction of *Time* or *InStyle* magazine to total weight of delivered mail. The exclusion of transportation emissions of the delivery of the magazine from the local post offices to customers may also be justified on the basis that the carriers would deliver mail to each household regardless of the presence of the magazines.

Final Fate of Magazines

Time Inc. provided data on the recovery rates for *Time* and *InStyle* newsstand and subscription magazines; these data were based on a several year average. Three potential fates of recovered old magazine grade (OMG) were considered: recycled for newsprint, incinerated, or landfilled. The fate of recovered magazines for recycling was approximated using OMG newsstand return statistics from Nationwide Magazine Recycling (Roy Threlkeld, personal communication). The estimated recovery rate of 17% for sold magazines was used to estimate the quantity of magazines that were recycled, with the balance either landfilled or incinerated. A detailed explanation of calculations of C emissions generated by the transportation of recovered OMG to newsprint facilities is provided in Appendix 4.

We assumed OMG was used once for newsprint with a lifespan of one year (Row and Phelps 1996, Skog and Nicholson 2000). This assumption does not account for newsprint that is recycled, but such data are sparse, and the carbon content of original OMG in recycled newsprint is small. Virtanen and Nilsson (1993) summarized the fate of wastepaper for eight countries in Europe for 1986, and Bilitewski (1993) summarized the fate of wastepaper in Germany for 1992. Both studies concluded that approximately 60-70% of wastepaper was placed in landfills. In the United States, approximately 90% of unrecovered OMG was landfilled, and the balance (10%) was incinerated (Paper Task Force 1995). For this study we used the data from the Paper Task Force.

The rate of decay differs by 200-fold among wood and paper products (Row and Phelps 1996). Aerobic fungi and bacteria are the dominant decomposers of organic matter both in forests (Landsberg and Gower 1997) and in wood and paper products (Skog and Nicholson 2000). When landfilled paper and wood are covered by waste material and soil, the environment quickly becomes anaerobic. As a result, little decay occurs, and methane (CH_4) is emitted (Wang et al. 1995, Micales and Skog 1997, Barlaz 1998). The fractions of newsprint and coated paper that decayed and released CO_2 or CH_4 during the lifespan of the paper product in the landfill were assumed to be 0.16 and 0.18, respectively; 40% was released as CO_2 and 60% was released as CH_4 (Skog and Nicholson 2000).

The temporal boundary of the study was 2001 because it was the most current year that data were available for all processes in the magazine and dimensional lumber chains. The implications of the temporal boundary are discussed in the discussion section.

RESULTS

Greenhouse Gas Emissions for the Dimensional Lumber Chain

Of the total wood harvested from the Chetwynd Forest in 2001, 52% was used to produce dimensional lumber, and the balance (48%), in the form of chips, was used to manufacture kraft pulp at the Intercon mill. A small fraction of the waste from the two primary product chains was used to manufacture other products, or used as biofuel (Figure 2).

Forest Management and Harvesting

Total wood harvested from the Chetwynd Forest in 2001 was 193,170 tons C, or 386,339 tons of dry biomass. The total CO_2-eq harvest emission for Chetwynd Forest in 2001 was 11,411 tons CO_2-eq, or 3,112 tons C, with wood hauling (48%) and felling (37%) comprising 85% of the total emissions (Table 1). GHG emissions from forest management and harvesting activities only comprised 1% of the total GHG emissions for the dimensional lumber chain (Figure 7).

Transportation of Wood Fiber to the Sawmill

The transportation of logs from the Chetwynd Forest to the Chetwynd sawmill released 1,342 tons CO_2-eq, or 366 tons C. Emissions for harvesting and transportation totaled 12,753 tons CO_2-eq, of which 6,632 tons CO_2-eq were attributed to the dimensional lumber chain, and 6,124 tons CO_2-eq were attributed to pulp production (Table 1). GHG emissions from transportation of the wood fiber to the sawmill comprised 1% of the total GHG emissions for the dimensional lumber chain (Figure 7).

Sawmill Production and GHG Emissions

Total dimensional lumber produced in 2001 at the Chetwynd sawmill was 121,888 Mfbm. Total GHG emission from the sawmill was 9,054 t CO_2-eq, of which 13% was from renewable energy sources. The GHG emissions from the sawmill comprised 2% of total CO_2-eq emissions for the dimensional lumber chain (Figure 7).

Transportation of Dimensional Lumber to the Consumer

The transportation and re-distribution of lumber from the Chetwynd sawmill to the consumer was the largest source of CO_2-eq emissions for the dimensional lumber chain (Figure 7, Table 1). The Home Depot purchased the largest amount of dimensional lumber produced by Canfor from the Chetwynd Forest in 2001, with the balance sold to other retailers throughout Canada and United States (Figure 2). The transportation emissions for 21,843 Mfbm of dimensional lumber via the Edmonton reload center and The Home Depot distribution centers (HDDC) to The Home Depot stores released 128,199 t CO_2-eq (Table 1). The high GHG emissions in this part of the product chain were in part explained by the sole use of trucks to transport the dimensional lumber from the HDDC to the stores.

The balance of the dimensional lumber (100,045 Mfbm) was transported and distributed to 22 locations. The transportation emissions for rail and truck were 56,952 t CO_2-eq and 26,444 t CO_2-eq, respectively, for a total of 83,396 t CO_2-eq.

Final fate of Dimensional Lumber

The final fate of the dimensional lumber was estimated to be 65% incinerated and 35% landfilled; 6% of the carbon contained in the wood that was landfilled was released to the atmosphere. The net emissions for the dimensional lumber chain are extremely sensitive to assumptions about the final fate of dimensional lumber (Figure 8), and illustrate the opportunity of recovery and re-use to reduce the GHG shadow of dimensional lumber. The analysis assumed the dimensional lumber waste was in a steady state--that is, that a constant fraction of the dimensional lumber produced each year is landfilled, incinerated, or recycled. In general, the production mix of forest products has been relatively stable in the past (Ruth and Harrington 1998).

In summary, the life-cycle analysis of the dimensional lumber chain revealed that 0.22 t C, or 0.81 t CO2-eq, were emitted per ton of dimensional lumber produced, and 97% of the emissions were indirect. The relative contributions of the processes in the dimensional lumber chain were: forest management and harvesting (1%), transportation of wood to the sawmill (1%), sawmill emissions (2%), transportation and distribution of dimensional lumber to consumer (94%), and miscellaneous losses from by-products and storage in waste products (2%).

Greenhouse Gas Emissions for the Magazine Chain

Forest Management and Harvesting GHG Emissions

Only GHG emissions from harvesting and skidding were included because site preparation and planting emissions were insignificant (see methods). Total GHG emissions from harvesting and skidding were 14,399, 2,225, and 1,427 t CO_2-eq for Wisconsin Rapids Pulp Mill, Biron Mill and Whiting Mill, respectively (Figure 9). Greenhouse gas emissions from harvesting comprised 2% of the total magazine chain emissions for both *Time* and *InStyle* (Figure 11).

Transportation of Wood Fiber and Clay to Pulp and Paper Mills

Total CO_2-eq emissions from the transportation of wood to SENA Wisconsin Rapids Pulp Mill, Biron Mill, and Whiting Mill were 25,097, 3,588, and 3,739 t CO_2-eq, respectively (Figure 9). Relative greenhouse gas emissions (t CO_2-eq per t wood) were consistently two times greater for Landing Trucked to Mill (LTM) mode of transportation than Rail to Mill (RTM) transportation (Figure 10). Relative greenhouse gas emissions for a given mode of transportation were consistent among the three SENA mills. Emissions data were available for transportation of wood fiber to the SENA WRPM for 1997-2001; emissions varied by 43% for chips and 38% for roundwood among the five years (not shown). However, the relative transportation CO_2-eq emissions varied only by 5% and 9% for chips and roundwood, respectively, among the five years. The data suggest that the larger inter-annual differences in absolute CO_2-eq emissions were largely attributed to inter-annual variation in the total amount of timber harvested. Validation of the assumption that the 2001 data are representative for the magazine and dimensional lumber chains is difficult, but these limited data for the transportation of chips suggest the assumption is reasonable.

In 2001, 82,143 and 42,755 tons of clay were transported by rail to the Biron Mill and Whiting Mill, respectively, and the total CO_2-eq emissions were 2,712 and 1,411 t CO_2-eq. Total CO_2-eq emissions for transportation of wood fiber and clay to the mills comprised 8% and 3% of total *Time* and *InStyle* magazine chain emissions, respectively (Figure 11).

Pulp and Paper Mill Production and GHG Emissions

The total (renewable plus non-renewable) CO_2-eq emissions for the three SENA mills were: Whiting (116,747 t CO_2-eq), Biron (419,575 t CO_2-eq), and Wisconsin Rapids Pulp Mill (WRPM) (1,149,827 t CO_2-eq). The percent of total mill emissions attributed to renewable, or carbon neutral, energy sources was 4% at the Biron Mill, 18% at the Whiting Mill, and 96% at the Wisconsin Rapids Pulp Mill (Figure 12). The lower emissions total for Whiting mill was partly due to the purchase of 80,565 tons of kraft pulp, or 29% of its annual pulp supply, from the Canfor Intercon and other Canadian kraft pulp mills (Figure 2). The annual GHG emissions from the Intercon kraft pulp mill for 2001 totaled 1,100,835 t CO_2-eq, or 300,255 t C. However, like the SENA WRPM, 94% of the total annual Intercon pulp mill emissions were attributed to renewable energy, or carbon neutral, sources (Table 1, Figure 12). CO_2-eq emissions per ton of paper produced differed by 10% between the Biron and Whiting paper mills (Figure 9). Total CO_2-eq emissions for pulp and paper production comprised 61% and 77% of total *Time* and *InStyle* magazine chain emissions, respectively (Figure 11). The ratios of kraft to mechanical pulp used to make paper at the Biron Mill and Whiting Mill were 0.38:0.62 and 0.42:0.58, respectively. The kraft pulp used at the Biron Mill was from the SENA Wisconsin Rapids Pulp Mill only, while the kraft pulp used at the Whiting Mill was from the SENA Wisconsin Rapids Pulp Mill and was purchased from outside kraft mills, including the Canfor Intercon mill.

Transportation of SENA Paper to Printers and Printer Emissions

Time Inc. printed 37,477 tons of paper for *Time* magazines at the six printers we studied (8,551 tons were printed at another printer that did not use SENA paper), and 22,539 tons of *InStyle* magazine were printed at a single printer in 2001 (Figure 13-14). The fraction of SENA paper used for printing *Time* at the printers ranged from 28-37%, and was 100% for *InStyle* (Table 2). Printer GHG emissions comprised 4% and 2% of total emissions for the *Time* and *InStyle* magazine chains (Figure 11). CO_2-eq emissions from the transportation of the magazines to consumers averaged 9% and 5% of total CO_2-eq emissions for *Time* and *InStyle* magazine chains (Figure 11).

Final Fate of Magazines

The estimated fate of *Time* and *InStyle* magazines is shown in Figures 13-14. In 2001, Time Inc. printed 22,539 tons of *InStyle* magazines, of which 56% (12,632 tons) went to newsstands and 44% (9,907 tons) went to subscribers (Figure 13). On average, 41% of the newsstand copies of *InStyle* (5,178 tons) were not sold. Approximately 7,869 tons, or 35% of total annual production, of *InStyle* magazines were recovered and recycled, but only 17% of subscription magazines were recovered. The sum of unrecovered newsstand and subscription magazines was estimated to be 14,670 tons. We estimated that approximately 13,203 tons of *InStyle* magazines were placed in landfills, based on an industry-wide average of 90% and 10% of unrecovered magazines which are landfilled and incinerated, respectively. The total unrecovered tonnage of *Time* magazines from newsstands and subscription was 25,730 tons, of which 23,157 and 2,573 tons were landfilled and incinerated, respectively. GHG emissions attributed to the final fate of *Time* and *InStyle* magazines comprised 16% and 10%, respectively (Figure 11).

The net CO_2-eq emission, or shadow, for *Time* magazines ranged from 1.01 to 1.25 t CO_2-eq/ton magazine, and the weighted average was 1.17 (based on tons of magazine produced at each printer) (Figure 15b). The net CO_2-eq emission for *InStyle* was 1.11 t CO_2-eq/ton magazine. The weighted net elemental C shadow for a ton of magazines averaged 0.32 and 0.30 t C/ton magazines for *Time* and *InStyle* magazines, respectively (Figure 15a). The differences between magazines cannot be attributed to printers because CO_2-eq emissions differed up- and down-stream of the printers due to different transportation distances and pulp sources. However, the C shadow differed by 5.8 fold between *Time* and *InStyle* when the shadow is calculated on a per magazine unit rather than magazine mass basis.

DISCUSSION

Greenhouse Gas Management and Forest Products

This study differs from most other GHG life cycle analysis for forest product chains because we largely used company-specific data, and the boundaries we defined were more encompassing than previous studies. We discourage readers from using the results from this study to extrapolate to other magazine and dimensional lumber chains until data from other LCA studies using similar boundary conditions are completed. For example, Côté et al. (2001) conducted a carbon mass balance analysis for an integrated pulp mill in Texarkana, Texas, that produces bleached board and cupstock grades of paper. The rolls of product are transported to other locations, where the paper is converted into milk and juice cartons. They concluded that the integrated mill and company forest were a net C sink by a factor of 1.4 to 2.8. (i.e., C sequestered by their forests exceeded the C released to produce the paper products by 1.4 to 2.8 times, depending upon assumptions used in the study). However, Côté and co-workers excluded many sources of GHG emissions, and they used questionable assumptions to estimate forest growth. Future forest product LCA studies should include all the major components of the life-cycle of the product, process or activity, encompassing: the extraction and processing of raw materials; manufacturing, transportation and distribution; use, re-use, and maintenance; recycling; and final disposal, including the release of CO_2 and CH_4 from landfills. Future LCA studies should explicitly define their boundaries and the processes that are included so that general patterns of GHG emissions for forest product chains can be developed and opportunities to reduce GHG emissions identified.

The magazine and dimensional lumber chains examined in this study were net C and GHG sources to the atmosphere--a direct contrast to conclusions reached by other scientists. The discrepancy between this study and other studies can be easily explained by the fact that all the other studies considered gross C storage in the paper or wood products. Such conclusions are misleading, and in the future, scientists should use the term "gross C storage" to denote the analysis does not include sources of GHG emissions. Despite the fact that the dimensional lumber chain was a net source of GHG emissions, the environmental shadows are less for dimensional lumber than for construction materials such as steel or concrete (Figure 16).

Uncertainties of this Study

Several assumptions were made in this LCA study which may influence the results. First, we assumed that harvesting does not affect the long-term soil C dynamics. The assumption was based on the conclusion of a meta-analysis of harvesting effects on soil carbon content (Johnson and Curtis 2001) and more recent case studies (Laiho et al. 2002, Gower et al. 2003, Yanai et al. 2001) which advise that results from chronosequence studies should be interpreted cautiously because harvest intensity and practices often change. The effects of disturbance on soil C pools are highly variable for several reasons: (i) varying disturbance and management intensities and their effects on soil and detritus C pools (Brais et al. 1995, Johnson and Curtis 2001, Wirth et al. 2002), (ii) inconsistent treatment or exclusion of some detritus C pools, the most common being coarse woody debris (Harmon et al. 1986), and (iii) past land use and historic disturbance legacies (Currie and Nadelhoffer 2002). Also, it is difficult to collect a sufficiently large sample size to detect statistical differences in soil C content from forest manipulations (Homann et al. 2001). All of these factors make it extremely difficult, if not impossible, to detect small changes in the C content of the large, and heterogeneous, soil C pool.